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ABSTRACT

Two experimental studies were conducted to compare two typical reading tasks--critical reading and proofreading--on computer display and on hard copy. Ten college freshmen with less than 10 total hours spent on a computer prior to the experiments were trained on the computer system for approximately three hours in two sessions before beginning the experiments. The computer display used for the experiments had a large, bit-mapped screen, variable fonts, and high resolution, black-on-white display. The first experiment compared subjects' efficiency at reading for meaning in one hard copy and four advanced computer conditions. Results showed a significant effect for screen size, with subjects' performance in large screen conditions approaching that of hard copy. There was no effect for text advancement method, nor was there an interaction between variables. The second experiment compared the same subjects' proofreading efficiency in large and small screen conditions and with hard copy. While the mean times for hard copy proofreading were slightly faster, the differences between the three conditions were not significant. (Author/HOD)

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Reading on the Computer: A Comparison of Standard and Advanced Computer Display and Hard Copy

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CDC Technical Report Series

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Reading on the Computer: A Comparison of Standard and Advanced Computer Display and Hard Copy

Abstract: Two experimental studies compared subjects' reading performance on computer screens and on printed hard copy. The computer display used for the experiments had a large, bit-mapped screen, variable fonts, and high resolution, black-on-white display. Experiment 1 compared subjects' efficiency reading for meaning in one hard copy and four advanced computer conditions. Variables in the four computer conditions (screen size and text advancement method) were crossed in a 2 x 2 design. Results showed a significant effect for screen size, with subjects' performance in large screen conditions approaching that of hard copy. There was no effect for text advancement method (scroll bar or function keys), nor was there an interaction between variables. Experiment 2 compared the same subjects' proofreading efficiency in two computer conditions (large and small screen) and on hard copy. While the mean times for hard copy proofreading were slightly faster, the differences between the three conditions were not significant.

Computer writers, even those who report that they like using a computer for writing tasks and find it a valuable aid to their processes, find it difficult to perform some tasks on the computer screen. In a series of interviews we found that writers often feel constrained by the machine when reading their texts critically, when attempting to reorganize, and when proofreading (Haas and Hayes, 1985b).

Writers often generate hard copies of their texts in order to deal with these cognitively demanding tasks. As computer use become more widespread in classrooms at every level, it seems appropriate to ask why readers and writers sometimes prefer hard copies of texts. An answer to this question would be useful to systems designers selecting features for new computer products, to psychologists interested in human-computer interaction, and educators concerned with the effect of the computer on learning processes. The studies detailed below explore two typical reading tasks--critical reading and proofreading--on computer display and on hard copy.

Experiment 1: Reading to Revise

Computer writers report difficulties in "getting a sense" of their texts when writing on the computer. Previous research (Haas and Hayes, 1985) indicates that spatial recall of text layout is constrained by the computer, and that retrieval of information from a previously read text is less efficient on a standard computer terminal than on hard copy. Subjects using a more advanced computer system, on the other hand, approach the efficiency of hard copy performance on spatial recall and information retrieval tasks. These simple reading tasks, at least, seem to be easier on an advanced computer system. However, critical reading requires forming a mental representation of a text's content and is a much more sophisticated skill than spatial recall or information retreival. This kind of reading is necessary for reading to revise or reorganize and it requires an understanding of the whole text, rather than a local interpretaion. This study explores whether whole-text reading to reorganize or revise is also affected by computer display.

This experiment was designed to answer this question by testing two hypotheses.

1. Reading for meaning ("making sense" of the text) would, like spatial recall and information retrieval, be adversely affected by the machine.

2. An advanced computer display would diminish the differences between subjects' performance in the computer and hard copy conditions. Specifically, display variables such as screen size and method of advancing the text were hypothesized as critical variables which would make reading for meaning on a computer screen more efficient.

The "text sense" task was to reorder a disordered text, and the specific computer design variables were:

--screen size: large and small
--text-advancement method: scroll bar or function keys

The task of reordering a disordered text was chosen as the task because it is a comprehension task with a spatial component, similar to detecting organization problems in a writer's own text.

The Computer: The computer system tested is one being developed by the Information Technology Center (ITC) at Carnegie-Mellon University. The machine is a SUN workstation with a nineteen-inch diagonal, bit-mapped, black-on-white display. The screen may contain a number of windows, of varying sizes and shapes. ("Screen" will be used to refer to the two window sizes used in the experiment.) Each screen contains a scroll bar, a graphic device for representing the size of the text and the position in the total text of the part currently being displayed. To change the display, e.g., move to the next section of text, or back to a previous one, the user "points" a mouse to a diffferent section of the scroll bar. The keyboard also contains

function keys for text advancement: *page forward, page back, beginning of file,* and *end of file.* The text-editor is one developed at the ITC and based on EMACS (Stallman, (1981) and SCRIBE.

Subjects: The subjects were 10 entering freshman with less than 10 total hours spent on a computer prior to the experiment. They were trained on the computer system for approximately 3 hours in two sessions before beginning the experiment.

Instrument: Five non-fiction texts, approximately 1200 words long and similar in readability, as measured by the Flesch Readbility Formula (Flesch, 1974), were altered so that complete lines of text were out of order. After scrambling, the lines of the text were numbered sequentially.

Task: Subjects read the disordered texts in five conditions: one hard copy condition and four computer conditions. The variables between computer conditions were screen size and text advancement method. The four conditions were:

1) large screen and scroll bar
2) small screen and scroll bar
3) large screen and function keys
4) small screen and function keys

The large screen was 10 inches long and 10 inches wide and held 46 lines of text; the small screen was 5 1/2 inches long and 8 inches wide and held 22 lines of text. This small screen approximates the size of a standard CRT or personal computer screen, while the large screen uses all the space available on the advanced machine.

The order of conditions was counterbalanced across subjects. Subjects indicated verbally how the lines should be reordered. The task was done orally (using the line numbers) to eliminate interference from motor variables; i.e., this experiment was designed to test only subjects' ability to "make sense" of a disordered text and not their ability to make the corrections to reorder it.

Analyses: A one-way analysis of variance was performed for all five conditions, and Newman-Keuls tests were run to determine which conditions differed significantly from other conditions. An additional two-way analysis of variance was performed for the four computer conditions to assess the relative importance of screen size and text advancement method.

Results: The mean time to complete the task was lowest in the hard copy condition (13.5 minutes), followed by large screen/keys (14.39), large screen/scroll bar (15.7 minutes), small screen/scroll bar (20.61 minutes), and small screen/keys (20.74 minutes). These times are listed in Table 1. As Table 2 shows, this difference in the scores for the five conditions is significant at the .001 level.

The Newman-Keuls analysis of the five conditions (presented in Table 3) shows hard copy and large screen conditions differing significantly ($p < .05$) from small screen conditions. However, this analysis shows no significant difference between large screen and hard copy conditions, and no

significant effect for text advancement method (the scroll bar/key variable).

The two-way analysis of variance (presented in Table 4) confirms this finding. There was a significant difference ($p < .01$) between the four conditions, with this same level of significance for the screen-size variable, no significance for the scroll bar/keys variable, and no interaction between the variables.

Discussion: The mean response times, which show an advantage for hard copy, seem to bear out interview subjects' reports of difficulties (see above) getting a sense of the text on a computer screen. These results are also consistent with results of previous studies involving recall and retrieval of information. (Haas and Hayes, 1985) However, a larger screen size appears to be a highly significant variable. The large screen conditions approached the hard copy condition in efficiency, and the small screen conditions were significantly less efficient than the large screen and scroll bar conditions.

The manner of moving through the text--whether by scroll bar or by function keys--does not appear to be a significant variable, nor does there appear to be an interaction between the two variables. Although there appears to be no difference in efficiency for scroll bar or function keys as a method of advancing the text, subjects in general preferred the scroll bar because they reported that it allowed them greater precision in moving through the text. Initial training on the scroll bar took longer than did training on the function keys, yet subjects--once they felt comfortable using the scroll bar--preferred it because of its accuracy.

Experiment 2: Proofreading on Computer and on Hard Copy

Writers also read their own texts to detect mechanical errors, and many computer writers report that they generate a hard copy of their text in order to proofread; (Haas and Hayes, 1985b) they assume that they are more accurate in detecting errors on paper than they are on the computer screen, and research confirms their reports. Wright and Lickorish (1983) found a signficant advantage ($p < .05$) in proofreading efficiency on printed hard copy, and Gould and Grischkowsky (1984) found that proofreading on hard copy was also significantly faster--205 word per minute for hard copy vs. 159 words per minute for CRT screen ($p < .01$).

Again, previous research leaves some questions unanswered. For instance, which computer display variables constrain or enhance proofreading efficiency? We might hypothesize that the differences between computer and hard copy efficiency found in the studies above result from poor quality display, and that more sophisticated computers--with improved bit-mapped displays, better resolution, variable fonts and type size, and larger screens--might alleviate computer constraints in detecting surface errors. Experiment 2 was designed to test this hypothesis by comparing subjects' performance proofreading in one hard copy and two computer conditions. Both computer conditions used the improved, black-on-white display described above; the difference between the two computer conditions in this experiment was in screen size.

Subjects: The same group of ten entering freshmen tested in Experiment 1 served as subjects in Experiment 2.

Instrument: Versions of three of the five texts used in Experiment 1 were used as the texts for this experiment. However, for this experiment the texts were not disordered but contained a number of errors: missing spaces, faulty mid-word capitals, repeated letters within words, and repeated words. These kinds of blatant errors, requiring little fine judgment of grammar and usage, were used so that the differences would likely be in actually seeing the errors rather than in detecting mistakes in spelling or usage. The texts were shortened to about 500 words each, and 24 errors were randomly placed in the texts.

Task: Subjects read the errored texts in three counterbalanced conditions. Again, the subjects indicated orally the corrections that should be made, to avoid interference from motor variables.

Conditions: There were three conditions: large screen, small screen, and hard copy. The screen sizes were the same as described above. Although variable fonts and type sizes are available on this computer system, they were not used so that the format would be identical to the hard copy. The subjects were allowed to use either scroll bar or function keys to move through the text.

Results: The mean response times for the three conditions were similar, with hard copy being the most efficient (5.1 minutes), followed by large screen (5.36 minutes), and small screen (5.44 minutes). However, the analysis of variance shown in Table 5 shows no significant difference between conditions. Accuracy in detecting errors remained high and consistent across subjects and across conditions and was not analyzed.

Conclusions: The results of this study show no significant difference between proofreading on hard copy and on an advanced, high quality computer display. These results--different from those of Wright and Lickorish (1983), and of Gould and Grischkowsky (1984)--may be attributed to any of several factors. Possibly the difficulty writers have detecting errors on standard terminals is relieved on this new, more advanced system. Both Gould et al, and Wright et al, used a standard CRT display with light on dark display. The black on white, high resolution display of the ITC's SUN workstation might be significantly more efficient for proofreading. While this experiment was not a replication of the Gould and Grischkowsky study, the lack of significant difference between hard copy and computer conditions might indicate that improved displays will alleviate the constraints writers' perceive in proofreading on the computer, and diminish the advantage for hard copy proofreading established in these earlier studies.

An alternative explanation might be that the different results are due to the tasks themselves: Gould and Grischiowsky had subjects proofread for eight hours; possibly the differences in condition efficiency do not show up in short tasks like this one. Even if the proofreading constraint is diminished by the new machine, this experiment did not test writers' *perceptions* of their difficulties proofreading. It may be that writers will still feel uncomfortable detecting errors on a more advanced computer screen, even if their performance is not hindered.

General Discussion

Difficulties in critical reading to revise or reorganize and proofreading on the computer screen are at least partly alleviated by new, more sophisticated computer displays. Subjects' performance in critical reading, or reading to get a "sense of the text," in a large screen condition approximates that of hard copy; both hard copy and large screen conditions show a significant advantage over small screen conditions. Similarly, subjects' proofreading on the improved display was not signficantly different from hard copy proofreading.

While these advances in computer design should be welcomed, further research is crucial, and should advance along two lines. First, educational researchers need to determine if and how the computer constrains and aids reading and writing. As computers become an ever-increasing presence in classrooms at all levels, teachers and researchers should explore how its presence will change the processes taught there. In addition, computer designers' decisions should be informed by a knowledge of how users use systems--both an analysis of their performance and a gathering of their responses--to encourage the use of computers by making them responsive and friendly, and to insure that important human skills, needs, and behaviors are not dictated by the medium.

Although business and industry are investing millions of dollars in computer systems for reading and writing documents and schools are acquiring computer systems for instruction, the effect of this new medium on reading and writing efficiency has not been thoroughly explored. While the computer may increase motivation in some circumstances and may make some tasks easier, it also presents users with new constraints.

Certainly the computer is here to stay in the classroom. However, research into how machines--and various features of machines--effect readers and writers should be explored for several reasons: first, research findings could inform future design choices and make machines more efficient and useful tools for communication. Second, educators at all levels should be informed of the nature of special problems that the computer presents to students as they read and write on the terminal. Third, research into reading and writing on the computer might help us to more accurately determine which aspects of these processes remain constant across media and so help us more thoroughly understand their essential character.

TABLE 1: Mean Scores for 5 conditions

Condition 1: large screen/scroll bar	15.7 minutes
Condition 2: small screen/scroll bar	20.61
Condition 3: large screen/function keys	14.39
Condition 4: small screen/function keys	20.74
Condition 5: hard copy	13.5

TABLE 2: ANOVA for 5 conditions

source	df	SS	MS	f	P
treatment	4	477.40	119.35	13.39	<.001
subjects	9	571.62	63.51	7.3	<.001
interaction	36	320.95	8.91		
total	47				

TABLE 3: Newman-Keuls test of significance

	hard copy	large screen/ keys	large screen/ scroll bar	small screen/ scroll bar	small screen/ keys
hard copy	***	8.90	22.03	71.08*	72.39*
large screen/ keys		***	13.13	62.18*	63.49*
large screen/ scroll bar			***	49.05*	50.36*
small screen/ scroll bar				***	1.31
small screen/ keys					***

*significant at α.05 level

TABLE 4: ANOVA for 4 computer conditions

source	df	SS	MS	f	p
subjects	9	403.08	44.79	4.25	<.01
conditions	3	325.34	108.45	10.30	<.01
screen size	1	316.62	316.62	30.07	<.01
mouse/keys	1	3.48	3.48	.33	NS
interaction	1	5.14	5.14	.49	NS
subjects X conditions	27	284.30	10.53		
total	39				

Table 5

ANOVA for 3 Conditions for Proofreading Experiment

Source	df	SS	MS	f	p
Treatment	3	.65	.21	.808	NS
Subjects	9	64.31	7.14		
Interaction	27	7.13	.26		
Total	36				

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